Hopi Arsenic Mitigation Project

Life Cycle Cost Analysis and Comparison of Arsenic Mitigation Alternatives:

HAMP Groundwater System and Village Arsenic Treatment Systems

Final Report

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Hopi Arsenic Mitigation Project
Life Cycle Cost Analysis and Comparison of Alternatives

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Abbreviations and Acronyms

AsIII – arsenite

AsIV – arsenate

bgs – below ground surface

ft – feet

FMCV – First Mesa Consolidated Villages

gal - gallons

GFH – granular ferric hydroxide

gpm – gallons per minute

HAMP – Hopi Arsenic Mitigation Project

hp – horsepower

hr - hour

IHS – Indian Health Service

KW - kilowatts

KWH – kilowatt hours

O&M – operation and maintenance

OMB – U.S. Office of Management and Budget

PER – preliminary engineering report

ppb – parts per billion

PV – present value

R&R – rehabilitation and replacement

RUL – remaining useful life

USEPA – United States Environmental Protection Agency

Executive Summary

This life cycle cost estimate and comparison of alternatives was developed as part of the Hopi Arsenic Mitigation Alternative Preliminary Engineering Report (PER) and is appended to the PER. It compares two water system alternatives for mitigation of current high arsenic concentrations in the groundwater supply of the First and Second Mesa Villages, namely:

1. Non-treatment alternative or Hopi Arsenic Mitigation Project (HAMP) system.

   This proposed water system provides groundwater with a low arsenic concentration from new wells located about 15 miles north of the mesas. The water would be conveyed by pipeline to the Villages and connected to the existing Village distribution systems. The existing Village wells would be disconnected.

   Two sub-alternatives were evaluated for the HAMP system: 1) primary power supply from the commercial electric grid, and 2) primary power supply from diesel generators at the wells and booster station.

2. Village arsenic treatment systems alternative

   This alternative provides arsenic treatment facilities in each Village to treat the high arsenic groundwater from existing and new Village wells. Three treatment facilities are proposed to serve 1) First Mesa Consolidated Villages (FMCV), 2) Shungopavi, and 3) Sipaulovi/Mishongnovi.

Initial capital costs, annual operation and maintenance (O&M) costs, and rehabilitation and replacement (R&R) costs were estimated for both alternatives for the 20 year design life. The present value of the total estimated costs of the water systems for the 20 year life was calculated, including the residual or remaining value of facilities with longer than 20 year life. The present value of the life cycle costs for the alternatives are summarized in Table S.1, including the two power supply sub-alternatives for the HAMP system.

In addition to the present value of the life cycle costs, non-cost considerations such as reliability and ease of operation were evaluated and compared. These impacts are summarized in Table S.2 and include the use of diesel generator power for the HAMP.

Table S.1 – Present Value Cost Comparison

Present Value of 20 Year Costs	HAMP with Grid Power	HAMP with Generator Power	Arsenic Treatment
Capital	$16,914,000	$14,588,000	$13,149,000
O&M	$7,032,000	$15,946,000	$12,502,000
R&R	$1,097,000	$1,457,000	$2,425,000
Total Present Value	$25,043,000	$31,991,000	$28,076,000
Remaining Useful Life Value	$7,232,000	$7,139,000	$3,520,000
Net Present Value	**$17,811,000**	**$24,852,000**	**$24,556,000**

Table S.2 – Comparison of Non-Cost Criteria

Non-Cost Criteria	HAMP	Arsenic Treatment
Complexity	Low	High
Operator Skills Required	Low	High
Reliability	Medium/High*	Medium
Sustainability	Medium/High*	Medium
Regulatory Compliance	High	Medium
Safety and Security	Medium	Medium
*Medium for generator power/High for grid power.		

Based on the comparison of the net present value of the life cycle costs, the HAMP system with grid power is clearly lower cost than the arsenic treatment alternative and the HAMP system with generator power. The HAMP system is also more appropriate for arsenic mitigation for the Villages considering non-cost factors.

1. Introduction

1.1 Objectives

This life cycle analysis and comparison of alternatives is an element of the Preliminary Engineering Report and the Water System Strategic Plan for the Hopi Arsenic Mitigation Project. GHD and OEM Services are performing this work as part of the Strategic Plan Supplemental Services authorized on September 27, 2013.

The objective of this analysis is to compare the estimated life cycle costs of two alternative water systems to mitigate high levels of arsenic in the existing wells for the Hopi Villages of Shungopavi, Upper and Lower Sipaulovi, and Upper and Lower Mishongnovi on the Second Mesa, and the First Mesa Consolidated Villages (FMCV).

The life cycle costs include estimated initial capital costs, operating and maintenance costs, and periodic replacement and rehabilitation costs for the selected design life cycle of 20 years. The total life cycle costs are calculated based on the present value; that is, the future costs in today's dollars. The present value of each alternative provides an equal basis of comparison of different types of water systems. Facilities included for each system alternative are intended to provide the same level of reliability and redundancy, based on current public water utility standards. After selection of the most appropriate alternative, more detailed assessment of facilities and costs, including detailed design, will be developed, and may be slightly different than presented in this analysis.

1.2 Non-treatment System Alternative (HAMP)

The non-treatment system alternative was proposed in the initial draft PER as the Hopi Arsenic Mitigation Project System (HAMP). It will be referred to as the HAMP system in this document, recognizing that all alternatives are intended to mitigate the arsenic in existing Village wells. This alternative consists of equipping and using the~~a~~ new well field approximately 15 miles north of the Second Mesa Villages, known as the Turquoise Trail wells. Wells have been drilled in this area, which ~~and~~ have arsenic concentrations less than 5 parts per billion and less than the EPA drinking water standard of 10 ppb. Therefore, no treatment is required for this groundwater. New water transmission lines would convey the groundwater to the first and second mesa Villages and connect to the existing Village water distribution systems. The existing Village wells would be disconnected. In addition to new wells, two new water storage tanks, a booster pump station, and disinfection facilities at the connection to each Village are included as part of the system.

Two sub-alternatives for the primary electrical power source for the HAMP system wells and booster station were considered: 1) primary power from the commercial electrical grid, and 2) primary power supplied by on-site diesel generators.

1.3 Village Arsenic Treatment Systems Alternative

The proposed Village arsenic treatment systems alternative consists of the construction of 3 arsenic treatment facilities for removal of arsenic from existing and new Village wells. The 3 treatment facilities would serve the three existing and separate water systems that serve the First and Second Mesa Villages: 1) Shungopavi, 2) the ~~combined~~ Villages of Sipaulovi and Mishongnovi, and 3) the ~~combined~~ Villages of the FMCV. In addition to the arsenic treatment facilities, new wells for redundancy, new water storage tanks, and interconnecting pipelines are included with existing wells and storage tanks to provide equivalent redundancy and reliability for life cycle cost comparison with the proposed HAMP system.

2. Background

2.1 Present Value (PV) Approach

The life cycle cost for each alternative is developed for comparison and to enable a selection of the most appropriate water system for the Hopi Tribe to eliminate high arsenic water from the Village drinking water systems. The intent of this analysis is to develop total costs for the design life of each alternative system. Total costs include initial capital costs, annual O&M costs, and periodic rehabilitation and replacement of the equipment and infrastructure as needed.

The current and future costs are converted to the cost in today's dollars, or the present value, using the forecasted value of money in the future. This is the reverse of collecting interest in the future on money deposited in a bank today. Converting all the costs to today's dollars enables equal comparison of the total life cycle costs, not just the initial construction costs. Capital costs are estimated in today's dollars (Year 2015), but O&M and R&R costs will accumulate over the life cycle of the facilities. These future costs are then converted to today's value using the predicted future value of money, known as the discount rate; like a reverse interest rate. The discount rate used in this analysis is established by the federal government and incorporates an estimated inflation rate.

Commented [B1]: Suggest including the discount rate used and the impliit inflation rate included in the discount rate. No need to keep people guessing on the numbers at this point.

2.2 Recommended Life Cycle

A life cycle of 20 years is selected for the analysis. This is based on the latest HAMP system design for a 20 year capacity. Accordingly, arsenic treatment systems are also sized for a 20 year life. The value of longer life facilities such as pipelines (75 years) are reflected in the calculated salvage value or, more accurately, the remaining useful life value for the comparison of alternatives.

Table A.1 in the Appendix provides a list of expected useful lives of all facilities and assets for both alternatives. This expected life assumes regular maintenance and rehabilitation. If the age and condition of the existing Village facilities incorporated in the arsenic treatment alternative are known (e.g. existing wells), those facilities are included in the determination of present value at their expected remaining useful life.

2.3 Basis of Cost Estimates

All cost estimates are at a conceptual or planning level for this analysis. The costs are based on comparable costs at similar facilities, standard construction estimating references, manufactures quotes, and GHD experience. Actual costs may vary by 20% (plus or minus) from these estimates.

2.3.1 Capital cost estimates

The capital costs for the HAMP system and the Village water treatment systems are based on IHS estimates in the PER. Capital costs for the arsenic treatment facilities are based on manufacturer's estimated costs, and costs calculated from standard construction estimating manuals such as Means, and on comparable facilities' constructed costs. The costs shown represent installed costs without a detailed breakdown of specific construction items such as labor or materials. For example, piping for wells and within the booster station and treatment facilities is included within the cost of the facilities and not identified separately.

Since the primary use of these costs is comparison of alternatives, the construction costs are based on estimated 2014 costs and not escalated through the construction period.

2.3.2` Operation and maintenance (O&M) cost estimates

O&M costs are developed based on operating requirements such as power and chemical usage, estimated labor requirements and hours, and similar unit costs. Table 2.1 lists the unit costs utilized in the O&M cost estimates. These are average or representative costs derived from quotes or costs for similar facilities in the area and include transportation to the Hopi Villages as appropriate. Some cost items such as parts and supplies are simply an allowance based on IHS and GHD experience at similar water systems. O&M unit costs are applied consistently for both alternatives.

Table 2.1 – O&M Cost Basis

O&M Cost Category	Unit Cost	
Operator	$17/hour	
Manager	$30/hour	
Personnel Benefits	25% of direct labor	
Electrical Power	$0.10/KWH	
Elec/Mech Equipment Efficiency	75%	New equipment
Diesel Fuel	$6.75/gal	
Hypochlorite Solution (12.5%)	$5/gal of solution	
Hydrochloric Acid (35%)	$6/pound of solution	
Service Vehicle O&M	$0.55/mile	

2.3.3 Rehabilitation and replacement (R&R) cost estimates

This section defines the requirements and costs for replacing and rehabilitating water system assets. As assets are used and age, they will need to be replaced. This replacement schedule is based on the estimated expected useful life for each asset category as listed in Table A.1 in the Appendices. Expected life is an estimate for planning purposes. Actual life may vary considerably due to operating conditions, environment, level of maintenance, and other factors.

Rehabilitation includes overhaul or refurbishment of major equipment and facilities that occur on a scheduled frequency, typically 5 years or more. These tasks may include for example, replacement of pump bearings, building roof replacement, and water storage tank painting. Rehabilitation is intended to keep assets in service and performing as intended for their expected life. Failure to perform rehabilitation, along with preventive maintenance, will result in shortened life of the asset. Preventive maintenance tasks are performed at least annually~~,~~ and included in the annual O&M costs.

Rehabilitation schedules and costs are based on general types of overhaul and refurbishment based on GHD knowledge and experience with similar water systems. Actual rehabilitation tasks and schedule will be based on manufacturers' recommendations.

To determine R&R costs, the water system facilities are divided into asset classes or categories, such as pumps, valves, tanks, etc. Each category is assigned an expected life for replacement, and a frequency for rehabilitation tasks. Replacement costs are generally equivalent to the initial construction costs, but may vary somewhat if some existing infrastructure will be reused. For example, a building may be replaced on an existing foundation, or a new pump re-installed on an existing concrete pad.

The total number of replacements and rehabs within the 20 year life present value life cycle is estimated. Due to the number of assets and asset categories, this approach is used in lieu of determining an R&R cost every year. After selection of the water system alternative, a schedule of R&R tasks and costs for that alternative will be developed to determine R&R annual funding needs and replacement reserve fund requirements.

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For the present value analysis, it is assumed that assets that expire at the end of the 20 years will not be replaced, and therefore not have a replacement cost, to be consistent with the design life of the systems. Similarly, if the asset has a useful life of 20 years, it will not be rehabilitated if scheduled for rehabilitation in year 20. If the asset has an expected life longer than the 20 year life cycle, rehabilitation costs are included for year 20 if scheduled.

The cost of replacement and rehabilitation is calculated in today's dollars, and thus represents the future costs of these replacements today for PV analysis purposes.

2.3.4. Remaining useful life (RUL) value estimates

Some assets, including some that are replaced during the 20 year life cycle, may have continuing use and value beyond 20 years. These may include assets with an expected age less than 20 years, but which have been replaced during the 20 year life cycle. It would be reasonable to expect that the selected water system would continue in service beyond 20 years. To reflect this continuing value, a remaining useful life (RUL) value is estimated using straight line depreciation of the original capital cost, and the number of years of remaining useful life beyond 20, until the end of the expected life.

The RUL value is not a true salvage value, but reflects the remaining or residual value at the end of 20 years for longer lived assets, assuming they will stay in use. Salvage of most used water system equipment and infrastructure typically costs more for the sale, removal, or demolition of the asset than the market value.

3. Village Arsenic Treatment Systems Alternative Description and Costs

Facilities and operations for both the HAMP system and the Village arsenic treatment systems are developed in accordance with current municipal utility standards for well run utilities. It is understood that this may not be the actual operating conditions when the system is implemented, but this assumption is necessary for a fair comparison between the proposed HAMP system and the conceptual Village treatment systems.

The utility standards include appropriate redundancy for reliability, such as standby equipment units and standby emergency power. The assumed standards also include a regular program of preventive maintenance, and of scheduled rehabilitation and replacement of the capital assets based on their expected useful life, which are included in the estimated costs.

3.1 Village Arsenic Treatment Process

The arsenic treatment systems are assumed to be essentially the same for each Village, but varying in size, and in facilities necessary to convey water to and from the arsenic treatment facility. The arsenic treatment facilities include the selected arsenic removal process, and appropriate chemical addition for pre-treatment of the groundwater for more efficient arsenic removal. There would also be a system for handling and disposing of backwash or wastes from the arsenic treatment process.

3.1.1 Arsenic removal process alternatives

Three categories of arsenic treatment were considered for evaluation and selection of an arsenic removal process. These include the general process categories of:

- Membrane processes
- Sorption processes
- Precipitative processes

The membrane process considered was a reverse osmosis membrane system. In this process, water is forced through membranes at pressures of 150 to 300 psi. The membranes remove most water contaminants in addition to arsenate and arsenite forms of arsenic. Chemical pre-treatment may be required depending on the groundwater characteristics. Pre-filtration would also be required to remove silt and turbidity. The amount of water waste is relatively high with the membrane process, since only a portion of the raw water can be passed through the membranes. The membranes must be chemically cleaned or replaced regularly.

Sorption processes include ion exchange and alumina based or iron based granular media. These processes remove arsenic by passing water through a media filter and exchanging arsenic ions with the media, or by adsorbing into the media. They typically require chemical treatment to control pH and other potential contaminants, and may require chemical oxidation to convert arsenite to arsenate for more effective removal. Periodically the media must be removed and replaced. There is some backwash waste from the media that may be high in arsenic.

Precipitative processes use chemical addition to the raw water to precipitate arsenic containing compounds that are then filtered out of the water. Other water contaminants may also be removed depending on the precipitating chemicals used. A relatively large waste stream or sludge is produced that may be difficult to handle and dispose of.

3.1.2 Arsenic processes cost comparison

Table 3.1 is a summary of the conceptual costs for the three treatment processes identified in the previous section. These costs are derived from general cost curves that are provided in the USEPA report *Arsenic Treatment Technology Evaluation Handbook for Small Systems*. They are based on Village treatment system capacity and updated to current costs based on an inflation index. These are costs for the process only and are used only for process comparison and selection. More complete estimates of the selected arsenic process system are provided in following sections of this report.

Table 3.1 – Estimated Arsenic Removal Process Cost Comparison

Arsenic Process Alternatives	FMCV	Sipaulovi/ Mishongnovi	Shungopavi	Totals
Membrane Process				
Capital Cost	$485,000	$168,000	$175,000	[=SUM(LEFT)]000
Annual O&M Cost	$114,000	$25,000	$53,000	$192,000
Sorption Process				
Capital Cost	$224,000	$93,000	$96,000	[=SUM(LEFT)]
Annual O&M Cost	$42,000	$12,000	$12,000	$66,000
Precipitative Process				
Capital Cost	$1,274,000	$527,000	$562,000	[=SUM(LEFT)]

Annual O&M Cost	$44,000	$12,000	$34,000	$90,000
Source: Arsenic Treatment Technology Evaluation Handbook for Small Systems. US EPA (816 R-03-014), 1993. Updated to 2015 dollars.				

3.1.3 Arsenic processes non-cost considerations

In addition to the capital and operating costs, a comparison of some significant non-cost considerations is also used to select the most appropriate process and summarized in Table 3.2. These considerations generally relate to the difficulty and complexity of the operation and maintenance of the process, as well as the performance efficiency and reliability. For example, chemical addition in the precipitative process is typically more technically complex and requires more operator time and skill than the other processes due to multiple chemical feed determinations and adjustments.

Table 3.2 – Comparison of Arsenic Removal Processes Non-Cost Criteria

	Membrane Process	Sorption Process	Precipitative Process
Arsenic removal	80 to 95%	95%	50 to 95%
Water Lost	15 to 40%	< 2%	< 10%
Chemical pre-treatment req'd	Maybe	Yes	Maybe
Pre-oxidation req'd	Yes	Yes	Yes
Waste stream	High Volume	Low	Medium, sludge
Operator skill req'd	Medium	Medium	High

3.1.4 Selected arsenic process description

Based on the cost and non-cost comparison in the previous sections, a sorption process is lower cost, more efficient, and easier to operate. It is selected as the arsenic treatment process for analysis and comparison with the HAMP system in this present value evaluation.

Additional and more specific information from arsenic treatment system manufacturers resulted in the selection of a package treatment system by Siemens as the basis for preliminary design and evaluation. The Siemens PV 2000 package system has a capacity of 100 gpm and uses granular ferric hydroxide (GFH) within low pressure steel vessels or tanks to adsorb the arsenic into the media as it passes through the vessel. The GFH is effective at removing arsenite and arsenate, but is most effective at removing arsenate. Therefore, oxidation of arsenite, along with adjustment of the groundwater pH below 8.5, is recommended for more efficient arsenic removal.

The media must be periodically backwashed to remove the build-up of solids, and must be periodically replaced as it becomes fully adsorbed or spent. The GFH will tolerate interferences such as vanadium, but since these elements are also adsorbed on the media, they may decrease the time between media replacements.

Other similar package systems are available and should be evaluated and selected during the design process. If arsenic treatment is selected as the desired alternative for the Villages, a more detailed analysis of the process and equipment system should be performed during the design of the water system for each Village. Water quality in each Village varies and may dictate the use of different sorption material and pre-treatment requirements.

The Siemens system is provided as a package system that includes media, media vessels or tanks, piping and controls. The system size for each Village was selected based on the estimated well capacities. The arsenic removal process is relatively easy to operate, but treatment and adjustment would be required. Village operators would perform daily equipment and process checks and adjustments. The removal and replacement of media, operations oversight, and regular and specialized system maintenance are assumed to be performed by the system contractor.

Associated with the adsorption treatment system is some chemical addition for pre-treatment of the well water to enhance the efficiency of the treatment, and to disinfect the finished water. Hydrochloric acid is added to reduce the high pH (9.7) of the groundwater to a pH range (7.5 to 8.5) for more efficient arsenic removal. Sodium hypochlorite solution is selected to oxidize or convert arsenic in the form of arsenite (AsIII) to arsenate (AsV) for more effective removal of the total arsenic. The hypochlorite is also used to provide a chlorine residual in the finished water.

The system requires periodic backwash of the media, typically about once per month. Backwash water would be supplied from the water system through a pressure and flow regulating valve. The backwash waste would be stored on-site and the system contractor would truck the backwash for disposal. Due to potentially high arsenic concentrations in the backwash waste, this liquid may need to be disposed as a hazardous waste.

Figure 3.1 is a schematic of the typical arsenic treatment system. Each arsenic process train consists of a lead and lag vessel. Two sets of treatment trains are provided at Shungopavi and Sipaulovi/Mishongnovi, with one as back-up, for redundancy and reliability. Three treatment trains are provided at FMCV, with one as back-up.

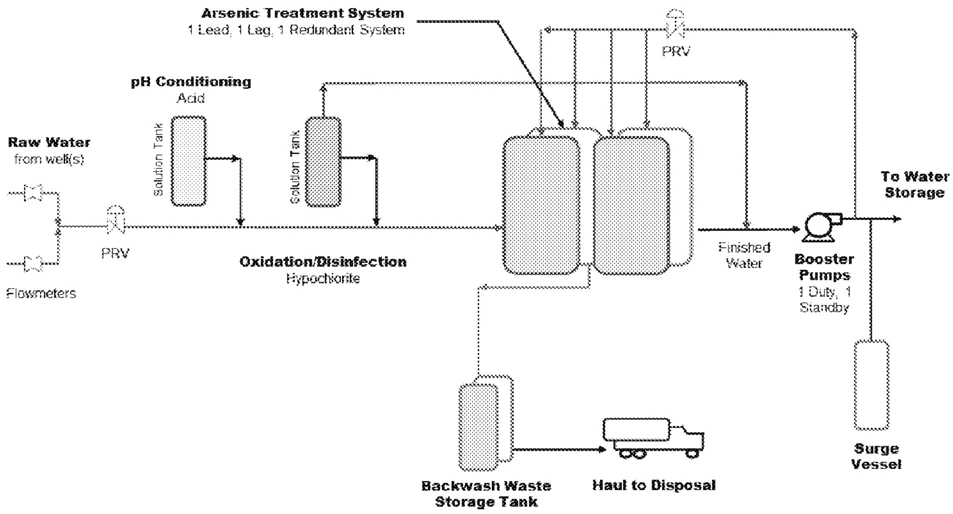

Figure 3.1 – Arsenic Treatment System Schematic

In addition to the arsenic removal process, other equipment systems are incorporated into the arsenic treatment facilities and included in the costs for the treatment facility.

The arsenic treatment system for each Village includes the following major components:

- Steel building and security fence
- 2 or 3 package treatment systems, 2 steel vessels for each system. One system is standby (FMCV has 2 operating systems and one standby.)
- Hypochlorite feed system (feed pump and controls)
- Hydrochloric acid feed system (feed pump and controls)
- Backwash waste storage tank

- Pressure regulating valves (on inlet and backwash lines)
- Finished water booster pumps, 2 pumps with one as standby
- Well flow meters

A typical arsenic treatment facility layout is shown on Figure 3.2 with dimensions of approximately 50 feet by 40 or 50 feet.

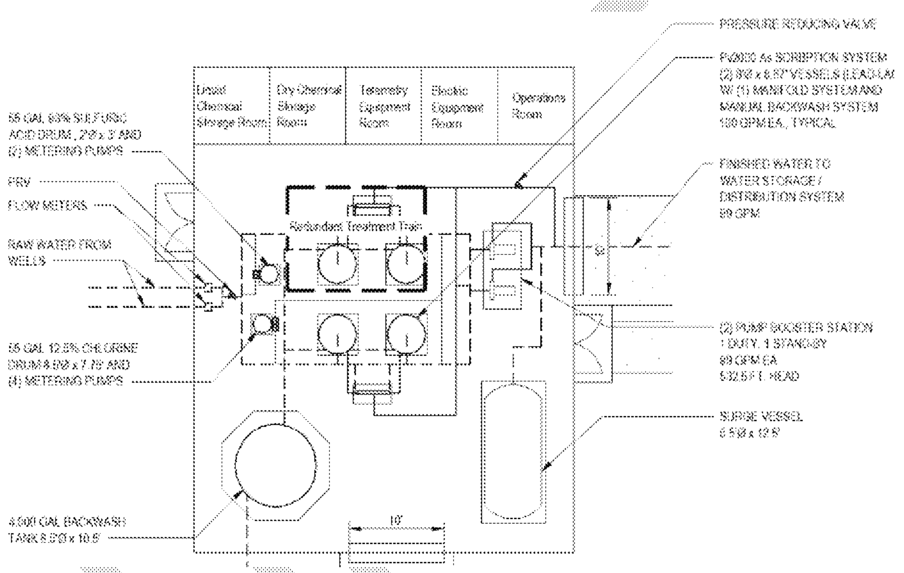

Figure 3.2 – Typical Arsenic Treatment Facility

3.2 Village Arsenic Treatment System Facilities

Water system facilities, in addition to the treatment facility, for each Village are described in the PER. They are summarized here as the facilities included in the life cycle cost analysis for the Arsenic Treatment alternative. These are conceptual facilities for evaluation and comparison of life cycle costs and would enable the systems to operate independently at a level comparable to the proposed HAMP system. They do not include facilities that would be utilized for both alternatives such as the existing Village distribution system and existing water storage tanks.

3.2.1 FMCV facilities and capital costs

Main facilities:

- Existing well 5, rehabilitated and with new standby generator
- Existing well 8
- Existing well 6 with new standby generator
- New well 9 with standby generator
- Power line extension to new well 9
- Arsenic treatment facility, located at well 8 with a standby generator for the treatment facility and well 8.
- New 200,000 gal tank adjacent to the East tank
- Interconnecting pipelines and appurtenances

Water would be pumped to the arsenic treatment facility, located at well 8. At peak day demand, 2 wells would be operating, with 2 in standby. After arsenic removal, the water would be pumped from the treatment facility to the existing East 500,000 gallon water storage tank and to a new 200,000 gallon storage tank that would be located adjacent to the East tank. Water will flow by gravity from the East tanks to the West tanks and the Villages. A structure to house the treatment system, backwash tank, electrical equipment, booster pumps, and related equipment is included, along with a standby generator for the existing well and treatment facility.

Table 3.3 – FMCV Arsenic Treatment Capital Costs

FMCV Facilities	Capacity/Quantity	Construction Cost
Existing well #5 rehabbed	100 gpm, 915 ft bgs, 40 hp	$ 65,000
Existing well #6	100 gpm, 915 ft bgs, 40 hp	0
Existing well # 8	110 gpm, 1,100 ft bgs, 40 hp	0
New well #9	100 gpm, 1,500 ft, bgs, 60 hp	$1,100,000
8” water pipeline and valves	29,150 feet	$1,081,000
New well power line extension	1.1 mile	$ 132,000
Roadway repair	2,450 feet	$ 84,000
Telemetry and controls		$50,000
Arsenic treatment facility	3 – 100 gpm trains	$702,000
New water storage tank	200,000 gallons	$ 260,000
Standby generator - Well #5	30 KW	$100,000

FMCV Facilities	Capacity/Quantity	Construction Cost
Standby generator – Well 6	30 KW	$100,000
Standby generator – new well 9	30 KW	$100,000
Standby generator – Well #8 and treatment facility	40 KW	$100,000
Tank Interconnects	2	$40,000
Altitude valve	1	$ 30,000
Total Construction Cost		**[=SUM(ABOVE)]**
Planning and Design		$190,000
O&M Support		93,000
Contingency & Other		541,000
Professional Fees		936,000
Total Capital Cost		**$5,704,000**

3.2.2 Shungopavi facilities and capital costs

Main facilities:

- New well (replacing the existing well which is beyond its useful life)
- Equipping an existing well not in service
- Arsenic treatment facility
- Standby generator for new well and treatment facility
- Standby generator for re-equipped well
- Connecting pipelines and appurtenances

Water would be pumped to the arsenic treatment facility from a new well (Well 1) adjacent to the existing well, and from a previous drilled well (Well 2) that would be equipped as part of the project. After treatment, water would be pumped to the existing elevated storage tank from the treatment facility. The treatment facility would be located adjacent to the existing Well 1. A structure to house the treatment system, backwash tank, electrical equipment, booster pumps, and related equipment is included, along with a standby generator for the existing well and treatment facility.

Table 3.4 – Shungopavi Arsenic Treatment Capital Costs

	Capacity/Quantity	Construction Cost
New well	35 hp, 65 gpm, 1600 ft	$ 885,000
Existing well #2 equipping	40 hp, 60 gpm, 1620 ft	$ 85,000
6" water pipeline & valves	5,150 feet	$ 66,000
Roadway repair	1,400 feet	$ 36,000
Arsenic treatment facility	2 – 100 gpm systems	$ 479,000
Telemetry and controls		$ 50,000
Standby generator - Well #1 & treatment facility	40 KW	$ 75,000
Standby generator Well #2	30 KW	$ 75,000
Tank interconnect		$ 20,000
Total Construction Cost		**$1,771,000**
Planning and Design		$ 70,000
O&M Support		$ 92,000
Contingency & Other	10%	$ 262,000
Professional Fees	18%	$ 503,000
Total Capital Cost		**$2,698,000**

3.2.3 Sipaulovi/Mishongnovi facilities and capital costs

Main facilities:

- New 100,000 gallon tank
- Lower Sipaulovi well replacement
- New east well (Rt. 264)
- Arsenic treatment plant at existing lower Sipaulovi well
- Standby generator at existing well and treatment facility
- Standby generator for new well
- Pipelines

The existing Lower Sipaulovi well would be replaced (Well 1), and an additional new well (Well 2) would be installed east of the existing well on Route 264 to provide redundant water supply. Water from both wells would be pumped to the arsenic treatment facility adjacent to the exiting well. From the treatment facility, the water would be pumped to a new 100,000 gallon water storage tank in Upper Sipaulovi. A structure to house the treatment system, backwash tank, electrical equipment, booster pumps, and related equipment is included, along with a standby generator for the new well (Well 2) and for the replaced existing well (Well 1) and treatment facility.

Table 3.5 – Sipaulovi/Mishongnovi Arsenic Treatment Capital Costs

	Capacity/Quantity	Construction Cost
New wells (2)	1000 ft, 40 hp, 100 gpm	$1,170,000
New well power supply		15,000
New storage tank	100,000 gal	170,000
Tank interconnect		$ 20,000
Flowmeter		$10,000
6" water pipeline and valves	19,500 ft	$598,000
Roadway	4,800 ft	$470,000
Roadway Boring	100 ft	$45,000
Arsenic treatment facility	2 – 100 gpm systems	$498,000
Telemetry and controls		$ 50,000
Standby generator – Existing well & treatment facility	40 KW	$75,000
Standby generator – new well	30 KW	$ 75,000
Total Construction Cost		**$3,196,000**
Planning and Design		$145,000
O&M Support		$92,000
Contingency & Other		$440,000
Professional Fees		$780,000
Total Capital Cost		**$4,653,000**

3.3 Arsenic Treatment Facilities Operation and Maintenance (O&M) Costs

Village arsenic treatment system O&M costs are developed using similar criteria to those used in the HAMP. It is assumed the Village operators will perform routine operation and maintenance tasks on both the treatment system and the associated Village water supply system. Maintenance of the Village distribution system is not included since it is the same for both the arsenic treatment and the HAMP system.

Specialized tasks and non-routine maintenance will be performed by arsenic system contractors and other specialty contractors. These include the following:

- Media replacement and removal
- Backwash disposal
- Arsenic system maintenance and repair
- Standby generator maintenance and repair
- Electrical and control equipment maintenance and repair
- Well and well pump maintenance and rehabilitation
- Major equipment and facility rehabilitation and replacement

3.3.1 O&M requirements and cost basis

For the arsenic treatment systems, it is assumed that Village operators would perform daily routine operating requirements that are listed in Table 3.6. These are representative average time requirements. For arsenic treatment, a Grade 2 water operator is recommended for the more complex operation, including chemical analyses and adjusting chemical dosages, backwash times, etc.

Table 3.6 – Typical Routine Operator Tasks and Time Requirements

Routine O&M Tasks	Frequency	Total Time
Check, inspect and record wells and storage tanks	Daily	2 hour/day
Check, inspect, test, & adjust arsenic treatment	Daily	4 hr/day
Maintain and clean arsenic facility	Weekly	4 hr/week
Collect, record & transport water samples to lab	Monthly	6 hr/month
Travel and admin time	Weekly	4 hr/week
Total Average Time		7.2 hr/day

To provide reliability and performance of the arsenic treatment systems, the treatment system manufacturer or similar qualified contractor would provide regular operations oversight and specialized maintenance. Table 3.7 lists the estimated contractor costs used to develop the O&M cost estimates. Differences in frequency or O&M costs reflect the difference in capacity and number of equipment systems between Shungopavi or Sipaulovi/Mishongnovi, and FMCV.

Table 3.7 – Estimated Contractor Costs for Arsenic Treatment Systems.

Maintenance Tasks	Avg. Frequency	Estimated Unit Cost
Replace/dispose media (2 vessels)	2 - 6 months	$2,000
Dispose backwash waste	3 - 6 months	$6,500
Maintain/adjust/troubleshoot treatment system	Monthly	$2,500
Maintain standby generator	Annually	$5,000
Well and pump inspection/troubleshooting	5 years	$10,000
Booster pumps	Annually	$3,000
Storage tank inspection	5 years	$10,000
Electrical equipment inspection & testing	5 years	$10,000
Control and instrument calibration	Annually	$5,000

3.3.2 Village arsenic treatment O&M costs

O&M costs for each Village are developed based on the estimated water usage in 2015 and the operating requirements for each system. Electricity, chemicals, residuals disposal, fuel/supplies and repairs will vary directly with the amount of water produced. Estimated water usage and production volumes are listed in Table 3.8.

Table 3.8 – Estimated Water Production (gallons per day average)

Year	FMCV	Shungopavi	Sipaulovi/ Mishongnovi	Totals
2015	142,000	29,500	26,300	201,800
2035	203,000	47,000	34,300	284,300

Each Village system has the same size Siemens process train capacity of 100 gpm, but FMCV will need 2 process trains to treat the water from two wells (140 to 150 gpm total), with one in standby. The FMCV system is higher cost due to larger arsenic treatment system capacity, and four wells that must be operated and maintained compared to two wells each for Shungopavi and Sipaulovi/Mishongnovi. Up to one and one-half, full time operators in each Village would be needed for routine daily operation duties for each treatment facility and wells. Labor and other costs for the distribution system and existing water tanks maintenance are not included.

A significant amount of contractor cost is included for the arsenic treatment systems to help ensure effective and reliable performance. These include media replacement, backwash disposal, and treatment process maintenance and operation oversight. Other contractor costs such as electrical and well maintenance are also assumed for the HAMP alternative.

Table 3.9 – FMCV Arsenic Treatment Estimated O&M Costs

O&M Cost Category	Estimated Annual Cost (Yr 2015)
Salaries and Benefits	$ 66,300
Administration	$ 34,500
Insurance	$ 4,000
Electricity	$ 65,000
Chemicals & Media	$ 32,000
Analytical	$ 5,500
Regular Maintenance/Repairs	$ 15,000
Specialized Contractor Maintenance	$ 60,000
Residuals Disposal	$ 40,000
Fuel/Supplies	$ 8,000
Vehicle O&M	$ 7,000
Miscellaneous & Contingency	$ 34,000
Total	**[=SUM(ABOVE)]**

Table 3.10 – Shungopavi Arsenic Treatment Estimated O&M Costs

O&M Cost Category	Estimated Annual Cost (Yr 2015)
Administration	$ 15,200
Insurance	$ 2,500
Electricity	$ 23,600
Salaries and Benefits	$ 44,200
Chemicals & Media	$ 5,600
Analytical	$ 5,500
Regular Maintenance/Repairs	$ 10,000

O&M Cost Category	Estimated Annual Cost (Yr 2015)
Specialized Contractor Maintenance	$ 40,000
Residuals Disposal	$ 20,000
Fuel/Supplies	$ 5,000
Vehicle O&M	$ 9,000
Miscellaneous & Contingency	$ 18,000
Total	$[=SUM(ABOVE)]

Table 3.11 – Sipaulovi/Mishongnovi Arsenic Treatment Estimated O&M Costs

O&M Cost Category	Estimated Annual Cost (Yr 2015)
Salaries and Benefits	$ 53,000
Administration	$ 8,500
Insurance	$ 2,500
Electricity	$ 23,800
Chemicals & Media	$ 5,500
Analytical	$ 5,500
Regular Maintenance/Repairs	$ 10,000
Specialized Contractor Maintenance	$ 40,000
Residuals Disposal	$ 20,000
Fuel/Supplies	$ 5,000
Vehicle O&M	$ 3,500
Miscellaneous & Contingency	$ 18,000
Total	[=SUM(ABOVE)]

3.4 Arsenic Treatment Rehabilitation and Replacement (R&R) Costs

Detailed rehabilitation and replacement costs for each Village arsenic treatment system alternative are provided in the Appendices, and summarized in Table 3.12. These are the estimated total R&R costs for the 20 year life cycle period. Assets that have reached their useful life at the end of 20 years are not replaced. Rehabilitation of assets that have a useful life beyond 20 years and are scheduled for rehabilitation in year 20 are included in the rehabilitation costs.

Table 3.12 – 20 Year R&R Costs for Village Arsenic Treatment

	Replacement Costs	Rehabilitation Costs	Total
FMCV	$1,316,000	$ 304,000	$1,620,000
Shungopavi	$ 64,000	$ 200,000	$ 264,000
Sipaulovi/Mishongnovi	$ 185,000	$ 356,000	$ 541,000
Arsenic Treatment Total	$1,565,000	$ 860,000	$2,425,000

3.5 Arsenic Treatment Alternative Cost Summary

The costs for arsenic treatment presented in this Section 3 are summarized in Table 3.13.

Table 3.13 – Cost Summary for the Arsenic Treatment Systems Alternative.

	FMCV	Shungopavi	Sipaulovi/ Mishongnovi	Totals
Total Capital Costs	$5,704,000	$2,798,000	$4,653,000	$13,149,000
Planning & Design	$ 190,000	$ 70,000	$ 145,000	[=SUM(LEFT)]
Construction	$3,944,000	$1,872,000	$3,196,000	[=SUM(LEFT)]
O&M Support	$ 93,000	$ 92,000	$ 92,000	[=SUM(LEFT)]
Contingency & Fees	$ 541,000	$ 262,000	$ 440,000	[=SUM(LEFT)]
Professional/Technical Services	$ 936,000	$ 503,000	$ 780,000	[=SUM(LEFT)]
Annual O&M Costs	$ 371,000	$ 199,000	$ 195,000	[=SUM(LEFT)]

Total R&R Costs	$1,620,000	$ 264,000	$ 541,000	[=SUM(LEFT)]

4. HAMP System Alternative Description and Costs

The proposed HAMP system was previously developed and described in the draft PER and is updated and revised in the current PER.

4.1 Facilities Description

The proposed HAMP capital facilities described in the PER are summarized as follows:

- Equipping the ~~W~~wells and installing booster pumps and controls at Turquoise Trail (2)
- Main 260,000 storage tank at radio towers and
- Booster station for Second Mesa
- Upper Sipaulovi 110,000 gallon storage tank
- Pipelines and valves
- Village connections and meters (3)
- Village chlorination facilities (3)
- Primary power for wells and booster station, either grid power or diesel generators (4)
- Roadwork

The HAMP system includes two sub-alternatives for primary power supply to the two wells and the booster station: 1) diesel engine generators, and 2) commercial power supply called grid power. The costs for both sub-alternatives are summarized in the following sections.

4.2 HAMP System Estimated Capital Costs

Capital costs vary between the sub-alternatives by one additional diesel generator for generator power, and for the power supply line for grid power. There will be 4 generators for the generator power sub-alternative, one for each well, since the wells are redundant, and two at the booster station to provide one standby primary power generator. The grid power alternative has 3 backup diesel generators, one for each well and one for the booster station.

Table 4.1 – HAMP Water System Capital Costs

HAMP Facilities	Capacity/Quantity	Grid Power	Generator Power
Wells Equipping (2)	400 gpm, 100 hp, 700 ft	$490,000	$490,000
Main Storage Tank & Controls	260,000 gal	388,000	388,000
Booster Station (4 pumps)	120 gpm @ 230 ft	190,000	190,000
Upper Sipaulovi Storage Tank	110,000 gal	165,000	165,000
Diesel Generators (4 for primary power, 3 for grid standby power)	2 - 375KW; 2 or 1 – 40KW	410,000	455,000
Power Supply Line	15 miles	1,800,000	0
12" Pipelines and Valves	75,300 ft	3,697,000	3,697,000
8" Pipelines and Valves	67,900 ft	2,447,000	2,447,000
6" & 4" Pipelines and Valves	33,900 ft	972,000	972,000
Pipeline Control Valves	8	170,000	170,000
Village Meters & Connections	4	100,000	100,000
Village Chlorination Facilities	3	165,000	165,000
Roadways	11,400 ft	923,000	923,000
Roadway Borings (3)	750 ft	360,000	360,000
Total Construction Cost		**$12,277,000**	**$10,522,000**
Planning and Design		75,000	75,000
O&M Support		407,000	407,000
Contingency	10%	1,276,000	1,100,000
Tribal Fees		353,000	305,000
Professional Fees	18%	2,526,000	2,179,000
Total Capital Cost		**$16,914,000**	**$14,588,000**

4.3 HAMP System Operation and Maintenance (O&M) Costs

O&M tasks and requirements are identified and discussed in detail in the PER and the Strategic Plan. The O&M costs in Table 4.2 include the costs of operation and contractor maintenance of the diesel generators for primary power at the Turquoise Trail wells and at the second Mesa booster station. Electricity costs included in Table 4.2 are for the Village chlorination stations and the proposed administration building.

Table 4.2 – HAMP Estimated O&M Annual Costs (Year 2015 $)

O&M Cost Category	Grid Power	Generator Power
Salaries and Benefits	$169,000	$169,000
Administration	$50,000	$50,000
Insurance	$15,000	$15,000
Electricity	$105,000	$6,000
Chemicals & Media	$7,000	$7,000
Analytical	$6,000	$6,000
Regular Maintenance/Repairs	$10,000	$10,000
Specialized Contractor Maintenance	$11,000	$80,000
Supplies	$10,000	$10,000
Diesel Fuel	$1,000	$526,000
Vehicle O&M	$8,000	$8,000
Miscellaneous & Contingency	$38,000	$88,000
Total	**$430,000**	**[=SUM(ABOVE)]**

Some costs will increase as a result of the planned increase in water production over the life of the project, irrespective of inflationary cost increases. These include electricity, chemicals, and maintenance.

4.4 HAMP Water System Rehabilitation and Replacement (R&R) Costs

R&R costs for the HAMP system sub-alternative vary because of the more frequent replacement of primary power generators for the generator power alternative. This equipment has a shortened life when operating continuously.

Table 4.3 – HAMP System Estimated 20 Year Replacement and Rehabilitation Costs (Year 2015 $)

	Grid Power	Generator Power
Replacement	$ 505,000	$ 855,000
Rehabilitation	$ 592,000	$ 602,000
Total R&R	$1,097,000	$1,457,000

4.4 HAMP System Alternative Cost Summary

The costs estimated in this Section 4 for the HAMP system are summarized in Table 4.4.

Table 4.4 – Cost Summary for the HAMP System Alternative

	HAMP with Grid Power Total Cost	HAMP with Generator Power Total Cost
Capital Costs	$16,914,000	$14,588,000
Planning & Design	$75,000	$75,000
Construction	$12,277,000	$10,522,000
O&M Support	$407,000	$407,000
Contingency & Fees	$1,629,000	$1,405,000
Professional/Technical Services	$2,526,000	$2,179,000
Annual O&M Costs (2015)	$430,000	$975,000
Total R&R Costs (20 Year)	$1,097,000	$1,457,000

5. Analysis and Comparison of Alternatives

This section provides a side by side comparison of the two water system alternatives, including the two sub-alternatives for the HAMP system, using the present value of the total costs for each system over the 20 year design life.

5.1 Present value calculation description

Determination and analysis of the life cycle costs of the HAMP system and the Village arsenic treatment systems is based on present value. The evaluation follows the guidance in the interagency engineering report for evaluating life cycle costs for IHS 86-121 projects, except as noted. Present value includes future costs in today's (Year 2015) dollars. Future costs are converted to today's dollars with a 'discount' rate based on the latest OMB rate which includes inflation.

The simplified calculation used herein includes capital costs and future renewal and replacement costs estimated in today's dollars. These costs are not inflated since application of the discount rate to the future inflated costs would result in the same cost as calculated today.

Annual O&M costs are increased based on an increase in water demand of 1.8% per year. This is a simplification since not all O&M costs will increase with an increase in water production. However, it is applied uniformly between the two alternatives and represents an equal comparison. A uniform gradient series factor is used to calculate the average annual O&M cost for the 20 year present value analysis life with a 1.8% per year increase. The present value of this average annual cost for the 20 year period is then calculated at the latest discount rate of 3.6% (20 years, with inflation - OMB, Dec 2013)

Estimated salvage value is not included, but a remaining useful life value is determined to identify assets that have useful life and value at the end of the 20 year design life. This is based on the assumption that the selected water system will continue to serve the Villages for some time after 20 years, rather than being abandoned.

5.2 Life Cycle Present Value Cost Comparison

Table 5.1 provides a comparison of the total life cycle costs for each alternative. Costs are developed and identified in this report and summarized here.

Table 5.1 – 20 Year Life Cycle Present Value Cost Comparison

	HAMP System with Grid Power	HAMP System With Generator Power	Villages Arsenic Treatment Systems
Capital Costs	$16,914,000	$14,588,000	$13,149,000
Annual O&M Costs	$ 430,000	$ 975,000	$ 765,000
O&M Present Value	$7,032,000	$15,946,000	$12,502,000
Renewal & Replacement Costs	$1,097,000	$1,457,000	$2,425,000
Total Present Value Cost	$25,043,000	$31,991,000	$28,076,000
RUL Value	$7,232,000	$7,139,000	$3,520,000
Net Present Value Cost	**$17,811,000**	**$24,852,000**	**$24,556,000**

The total present value cost comparison indicates that the HAMP system with grid power is significantly lower cost than the HAMP system with generator power or the arsenic treatment alternative. While the capital costs for this alternative are higher, the O&M and R&R costs are significantly lower, thus reducing the life cycle costs.

5.3 Non-Cost Comparison

5.3.1 Non-cost criteria

Complexity of operation

The complexity is measured by the type and number of tasks necessary to operate and maintain the system. Treatment systems tend to be more complex since there are daily and often hourly adjustments that may be needed, often based on laboratory testing by operators.

Operator skills required

Similar to complexity, the operator skills necessary to monitor and adjust the processes and perform routine maintenance of the equipment systems will vary according to the type of chemical and mechanical systems involved. Chemical treatment and adjustment may require more skill, but complex automation and control systems may also require higher level operator skills for troubleshooting and correcting problems.

Reliability

Reliability is measured by the capability of the system to operate under foreseeable conditions. Both conceptual systems have a high level of redundancy and both involve the equivalent levels of pumping. Both alternatives have single pipelines that could fail and cause the loss of water supply. The HAMP system with primary power from diesel engine generators tends to be more vulnerable to failure including fuel delivery failure, engine failure, and controls failure.

Sustainability

Typically related to energy use, sustainability also considers future changes including regulations and technology. Will the system be able to continue in the future if there are substantial changes in energy availability or cost, or if treatment chemicals or diesel fuel cannot be obtained or can only be obtained at higher cost? Similarly, controls and electrical systems are susceptible to technology changes that could ~~prevent~~ eliminate the availabilityle of spare parts.

Safety and Security

Safety and security considers worker health and safety, security of the water system facilities, and impacts on the community. All water systems can be vulnerable to damage from vandalism, but remote facilities tend to be less secure. Hazardous chemicals and high strength backwash waste streams from arsenic treatment present a potential health and safety hazard to workers.

Regulatory

All system alternatives are designed to meet current drinking water arsenic limits. Failure of the arsenic treatment process could cause the limits to be exceeded until corrected. There is a likelihood of lowered arsenic standards in the future. This could require additional processes and costs for the arsenic treatment alternative. Based on preliminary water quality analysis, the HAMP wells would be able to meet a future standard of 5 ppb.

Commented [B3]: Are the results of the tests final,now?

5.3.2 Non-cost comparison

Each alternative is rated on a relative basis for each non-cost criteria and summarized in Table 5.3 The HAMP rating includes a different rating for reliability and sustainability with the generator power sub-alternative rating lower or medium in both. Grid power provides improved reliability and sustainability of the HAMP system in comparison to the continuous operation of diesel engine generators.

The comparison in Table 5.3 indicates that the HAMP system rates better in most of the non-cost criteria and specifically better in performance and operating requirements than the arsenic treatment alternative. Grid power provides improved reliability and sustainability of the HAMP system in comparison to the continuous operation of diesel engine generators.

Most importantly, since the HAMP groundwater meets current drinking water standards for arsenic, it does not need to rely on a more complex treatment system in each Village to achieve the primary goal of arsenic mitigation.

Table 5.3 – Non-Cost Rating and Comparison

Criteria	HAMP	Arsenic Treatment
Complexity	Low	High
Operator skills required	Low	High
Reliability (grid/generator)	High/Medium	Medium
Sustainability (grid/generator)	High/Medium	Medium
Regulatory compliance	High	Low
Safety & Security	Medium	Medium

6. Conclusions

Comparison of the present value of the life cycle costs of the HAMP system sub-alternative with grid power, and the Village arsenic treatment systems alternative indicates the net present value of the HAMP system with grid power is the lowest cost solution and the preferred alternative.

Comparison of non-cost factors also favors the HAMP alternative because it is a more reliable, longer-term system that is less complex to operate and maintain. It also provides an advantage of extended life beyond the 20-year life cycle selected for this present value analysis. Non-cost factors are also reflected in the life cycle costs. For example, the complexity of chemical processes for arsenic treatment is addressed by including costs for contractor oversight and maintenance of these systems. Recent experience with similar types of systems at Keams Canyon and at the Upper Village of Moenkopi reinforces the difficulty of operating and maintaining these types of systems in the Hopi Villages.

Using electrical power from the commercial grid, the HAMP system will have a considerably lower life cycle cost than the arsenic treatment systems and the HAMP alternative with diesel generator power, and will be more reliable than both. The HAMP system with diesel generators as the primary power source nearly doubles the O&M costs of the HAMP system, and greatly increases the life cycle costs for a 20 year period, and is not recommended.

Based on the net present value and life cycle cost analysis, the HAMP system sub-alternative with grid power is the preferred alternative for arsenic mitigation of the water supply for the Hopi Villages on the First and Second Mesas.

APPENDIX

Estimated Asset Useful Life and Rehabilitation Frequency

Asset Category	Expected Useful Life[1]	Estimated Rehabilitation Frequency[2]
Wells (casing & screens)	40	15
Well Pump, Motor, & Column	30	10
Structure/Building	40	15
Water Storage Tank	40	15
Electrical Equipment	30	10
Control/Telemetry Equipment	10	none
HVAC Equipment	20	5
Standby Diesel Generator	25	5
Primary Diesel Generator	10	5
Surge Tank	30	10
Surge Tank Air System	15	5
Chemical Feed Pumps	10	5
Altitude Valves	20	5
Pipelines	75	none
Valves, Isolation	30	15
Pressure Regulating Valves	20	5
Air Release Valves	20	5
Flowmeters	25	10
Backflow Preventers	20	5
Booster Pumps & Motors	20	10
Vehicles	6	3
Arsenic Treatment Process	20	5

[1]Based on regular preventive maintenance and rehabilitation. For planning only. Actual life will vary with the service requirements and other conditions.
[2]General estimate of frequency for major overhaul or refurbishment for analysis and planning purposes only.